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SEDIMENTOLOGY OF THE LATE PLEISTOCENE IRONSHORE FORMATION ON GRAND CAYMAN

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ABSTRACT

The Ironshore Formation on Grand Cayman comprises 13 facies which were deposited in the Ironshore Lagoon. Bivalve Facies A and B, in the interior of the lagoon, consist of abundant bivalves in a matrix of poorly to moderately sorted carbonate silt to fine-grained sand. These allochems are predominantly micritized skeletal grains, Halimeda, and benthic foraminifera. Bivalve Facies A is located in the extreme interior of the lagoon and is finer grained and contains more foraminifera and fewer corals than Bivalve Facies B.

Coral Facies A includes a series of patch reefs, which formed near the westward opening of the lagoon. These patch reefs, from 2-3 m to over 300 m in diameter, are dominated by Montastrea, Diploria, Porites, Siderastrea, and Agaricia. The larger patch reefs, which show a distinct zonation, have a higher diversity than the smaller patch reefs, which are commonly monospecific. The Skeletal Grainstone, Moderately Burrowed Grainstone, or Highly Burrowed Grainstone facies were deposited between the patch reefs.

Coral Facies B comprises a diverse assemblage of corals, similar to those in the patch reefs, but also containing Meandrina, Acropora, Pocillopora, and Dendrogyra. These corals grew in a reef tract across the western edge of the lagoon, in a back reef environment. The Well Sorted Skeletal Grainstone Facies crosses Coral Facies B and was deposited in a series of channels through the reef tract.

The Multidirectional Cross-bedded Grainstone Facies consists of ooid grainstones that probably formed in an upper shoreface environment. This facies, which overlies Coral Facies A and B and associated facies, contains abundant marine trace fossils, which are found up to 4 m above present-day sea level. Erosional channels into this facies contain the Unidirectional Cross-bedded Grainstone, Lithoclast Rudstone, and Bioclast Floatstone facies.

The Multidirectional Cross-bedded Grainstone Facies is overlain by the Laminated Grainstone Facies, also consisting of ooid grainstones. This facies, which occurs up to 6.5 m above present-day sea level, is interpreted to be a foreshore (beach) deposit.

INTRODUCTION

Matley (1926) named the Ironshore Formation for the Pleistocene limestones that overlie the Oligocene-Miocene Bluff Formation on the Cayman Islands. The formation, which is up to 30 m thick (Brunt et al., 1973), is best exposed on the western part of Grand Cayman where the bedding is horizontal. The formation, 125,000 years old according to U-Th dating (Woodroffe et al., 1983), correlates with many other late Pleistocene sequences in the Caribbean (e.g. Broecker et al., 1968; Neumann and Moore, 1975; Harmon et al., 1981). Although Brunt et al. (1973), Rigby and Roberts (1976), Woodroffe et al. (1980), Jones and Goodbody (1984), Jones and Pemberton (1988a, 1988b, 1989), Hunter and Jones (1988, 1989), and Jones and Hunter (in press) discussed various aspects of the sedimentology of the Ironshore Formation, there has been no attempt to produce an overall synthesis.

The height of sea level in the Caribbean, 125,000 years ago, was approximately 5-6 m above current sea level (e.g. Neumann and Moore, 1975; Harmon et al., 1981; Carew et al., 1984; Brasier and Donahue, 1985). On Grand Cayman, however, Woodroffe et al. (1983) and Woodroffe (1988) placed the last interglacial sea level at 2-3 m above present day sea level. This was based on an erosional terrace at about 2 m (Emery, 1981) and a wave cut notch at 2.3-2.5 m on the southwest coast (Woodroffe et al., 1983, p. 71). There is, however, a 6 m terrace (Emery, 1981) and a wave cut notch at about 6 m on the northwest coast of Grand Cayman (Jones and Hunter, in press) which corresponds to a wave cut notch at 5.5-7 m on Cayman Brac (Woodroffe et al., 1983). These data supplemented with sedimentological data, suggest that the sea level during the deposition of the Ironshore Formation was at about +6 m on Grand Cayman (Jones and Hunter, in press).

Following a preliminary study of the Pleistocene geology of Grand Cayman, Hunter and Jones (1988) suggested that most of the Ironshore Formation was deposited in a lagoon, which they termed the Ironshore Lagoon. With respect to the Ironshore Formation, this paper (1) compares the facies as described by different authors, (2) describes the sedimentology of these facies, and (3) comments on the paleogeography at the time of deposition.

METHODS

The western part of Grand Cayman is low lying (most < 2 m above sea level) and usually covered with mangrove swamps. Thus, apart from coastal exposures on the southwest and northwest coasts and two quarries, good exposures of the Ironshore Formation are rare. Data for this study were obtained from (1) transects of 3 km along the southwest coast and 4 km along the northwest coast, (2) excavations associated with the construction of canals in the interior of the island, (3) exposures along the west coast of North Sound, and (4) exposures in Paul Bodden Quarry (PBQ, PBA) and Botabano Quarry (BQ). One hundred thirty eight localities were examined in the Ironshore Formation (Fig. 1B).

Grain size and sorting was determined qualitatively from thin sections using a microscope with a micrometer eyepiece. Skeletal types were determined from thin section microscopy by comparing them to thin sections of known skeletal material and published descriptions (Bathurst, 1975; Scholle, 1978). Two hundred thirty three thin sections were used in these analyses.

FACIES OF THE IRONSHORE FORMATION

Introduction

Thirteen facies are present in the Ironshore Formation on Grand Cayman (Table 1, 2). Although some facies have been described before, they were used for different purposes and thus simplified and generalized (Table 1). A detailed geology map of the island has been drawn based on extensive field work completed on the island (Fig. 2, 3).

Bivalve Facies A

This limestone, which is only found in the extreme interior of the Ironshore Lagoon, is characterized by abundant bivalves in a skeletal wackestone to packstone matrix (Table 2). This facies occurs at Midland Acres (MA) and Tarpon Springs Estates (TSE - Fig. 1B).

Bivalve Facies A contains a diverse assemblage of molluscs (70 species), that is dominated by Linga pensylvanica, Anodontia alba, Bulla striata, Cerithium spp., and Tellina candeana (Rehder,

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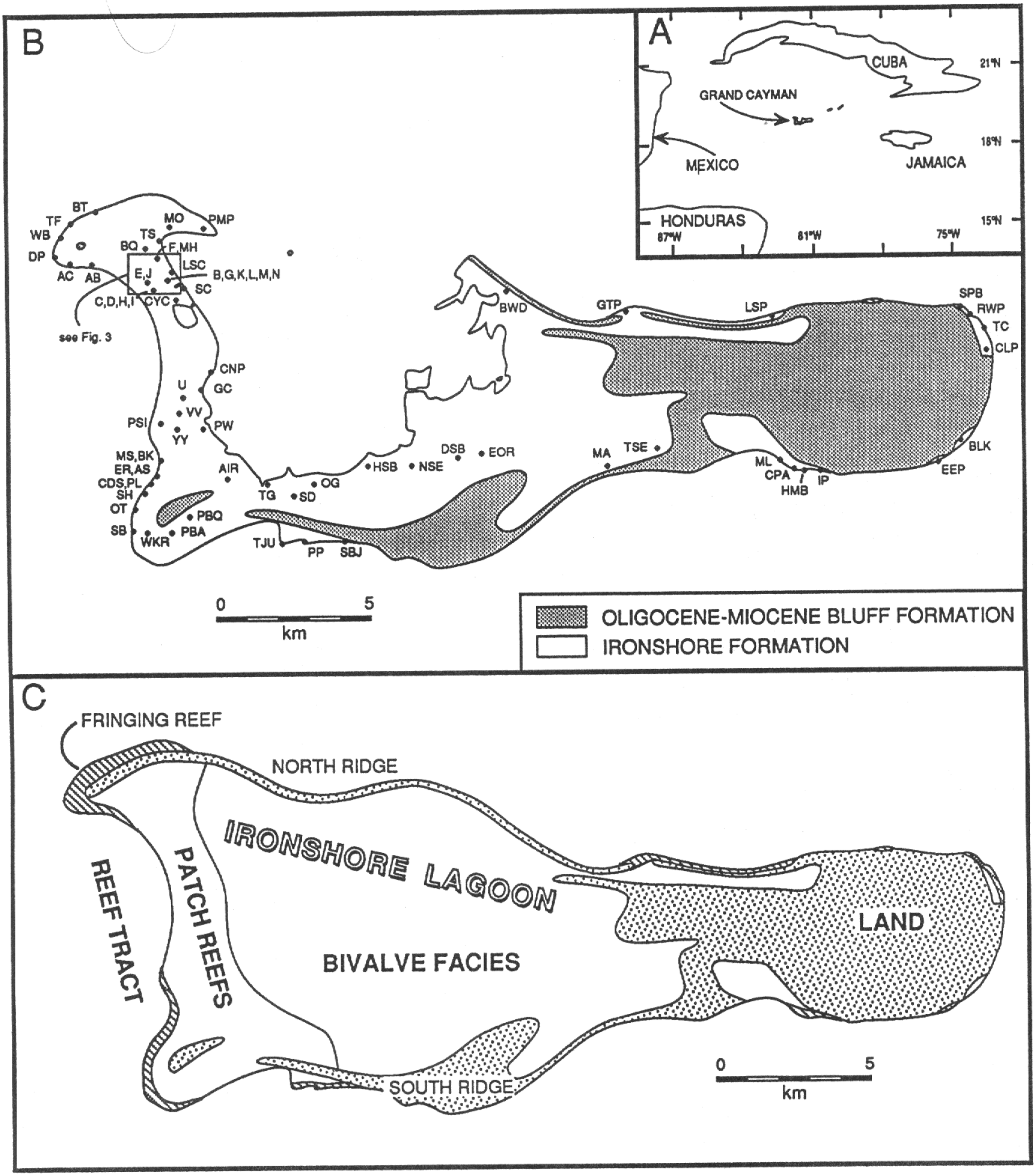

Figure 1. A) General location of the Cayman Islands in the Caribbean. B) Geological map of Grand Cayman with locations mentioned in the text. C) Paleogeographic map of Grand Cayman 125,000 years ago (modified after Hunter and Jones, 1988).

1962; Brunt et al., 1973; Cerridwen, 1989). The bivalves, commonly articulated, show no evidence of abrasion. Although molluscs generally lose their colour quickly (Parsons, 1989), some bivalves, such as Argopecten nucleus and Chione paphia (Cerridwen, 1989), retained their original colour. This may reflect rapid burial and little mechanical movement. This bivalve assemblage, dominated by burrowing bivalves, is indicative of a lagoonal environment, either in grass meadows or on a sandy bottom (Hunter and Jones, 1988; Cerridwen, 1989). Corals are very rare in this facies.

The dominant allochems in the matrix of this limestone are micritized skeletal grains, foraminifera, and Halimeda fragments,

<table>
<tr><th>Brunt et al. 1973</th><th>Woodroffe et al. 1980</th><th>Jones and Goodbody 1984</th><th>Hunter and Jones 1988</th><th>Hunter and Jones 1989</th><th>Jones and Hunter in press</th><th>Jones and Pemberton 1989</th><th>This paper</th></tr>
<tr><td rowspan="4">Lagoonal Facies</td><td rowspan="2">N/A</td><td rowspan="2">N/A</td><td rowspan="2">Bivalve Facies</td><td>Facies A</td><td rowspan="2">Bivalve Facies</td><td>N/A</td><td>Bivalve A</td></tr>
<tr><td>Facies B</td><td>N/A</td><td>Bivalve B</td></tr>
<tr><td>Coral bearing facies</td><td rowspan="2">N/A</td><td rowspan="2">Lagoonal environment Patch reefs</td><td>Facies C</td><td>Coral Facies A</td><td>N/A</td><td>Coral A</td></tr>
<tr><td>Lagoonal facies</td><td>Facies D</td><td>Laminated to highly burrowed grainstone</td><td>N/A</td><td>Skeletal Grainstone</td></tr>
<tr><td>Reef Facies</td><td rowspan="2">N/A</td><td rowspan="2">N/A</td><td rowspan="3">Reef Tract</td><td rowspan="2">Facies E</td><td rowspan="3">Coral Facies B</td><td rowspan="2">N/A</td><td rowspan="2">Coral B</td></tr>
<tr><td>Back-reef Facies</td></tr>
<tr><td>N/A</td><td>N/A</td><td>N/A</td><td>Facies F</td><td>N/A</td><td>Well Sorted Skeletal Grainstone</td></tr>
<tr><td rowspan="9">Shoal Facies</td><td rowspan="9">Oolitic Facies</td><td rowspan="2">Facies B</td><td rowspan="9">Ooid Facies</td><td rowspan="9">Facies G</td><td rowspan="3">Laminated to highly burrowed grainstone</td><td>Facies A</td><td rowspan="2">Moderately Burrowed Grainstone</td></tr>
<tr><td>Facies B</td></tr>
<tr><td>Facies A</td><td>Facies C</td><td>Highly Burrowed Grainstone</td></tr>
<tr><td>Facies C</td><td>Unidirectional high-angle cross-bedded grainstone</td><td>Facies D</td><td>Unidirectional Cross-bedded Grainstone</td></tr>
<tr><td rowspan="4">N/A</td><td>Multidirectional high-angle cross-bedded grainstone</td><td>Facies E</td><td>Multidirectional Cross-bedded Grainstone</td></tr>
<tr><td rowspan="2">Rudstone</td><td>Facies F</td><td>Lithoclast Rudstone</td></tr>
<tr><td>Facies G</td><td>Bioclast Floatstone</td></tr>
<tr><td>Laminated to low-angle cross-bedded grainstone</td><td>N/A</td><td>Laminated Grainstone</td></tr>
</table>

Table 1. Correlation of facies names of the Ironshore Formation as used by different authors on Grand Cayman. N/A = not applicable.

along with lesser amounts of red algae, mollusc, coral, and echinoid fragments (Fig. 4A). The rock contains up to 20% benthic foraminifera, mainly peneroplids (Fig. 4B). The micritized skeletal grains (1) are 30-125 µm in diameter, (2) contain no skeletal fragments, (3) are angular in shape, and (4) do not contain canal systems. Collectively, this suggests that they are micritized skeletal grains rather than pellets.

Bivalve Facies B

Between the extreme interior of the Ironshore Lagoon (Bivalve Facies A) and the area of patch reefs (Coral Facies A) is a facies characterized by bivalves in a skeletal packstone to grainstone matrix (Table 2). This facies occurs at the End of the Road (EOR), Duck Pond Bight (DSB), North Sound Estates (NSE), Head Sound Barcadere (HSB), Omega Gardens (OG, OGA), Tropical Gardens (TG), and Bowseland (BWD - Fig. 1B).

The main difference between the Bivalve Facies A and Bivalve Facies B is that the former is finer grained, contains more foraminifera (up to 20% of the rock), and has fewer corals.

Bivalve Facies B contains a diverse assemblage of molluscs (Rehder, 1962; Brunt et al., 1973; Cerridwen, 1989), with 79 species of molluscs recorded by Cerridwen (1989). The preservation of the molluscs is similar to that in Bivalve Facies A (Hunter and Jones, 1988). Although this facies and Bivalve Facies A were grouped together by Cerridwen (1989), the mollusc assemblage is slightly different, being dominated by Chione spp., Codakia spp., Anodontia alba, Crassinella martinicensis, and Cerithium spp.

FACIES	LOCALITIES	LITHOTYPE	SORTING	GRAIN SIZE	SEDIMENTARY STRUCTURES	FOSSILS		TRACE FOSSILS*	ENVIRONMENT
						DOMINANT	MINOR		
Bivalve A	MA, TSE	skeletal wackestone to packstone	poor	silt to very fine	N/O	bivalves	gastropods, foraminifera	N/O	Lagoon
Bivalve B	EOR, DSB, NSE, OG, OGA, HSB, BWD, TG	skeletal packstone to grainstone	moderate to poor	very fine to fine	N/O	bivalves	corals, Halimeda, gastropods	N/O	Lagoon
Coral A	MOS, MH, A, B, C, D, E, F, G, I, J, K, CYA, CYB, CYC, PSI, VV, YY, PBA, PBQ, WKR, SDA, SDB	coral floatstone	poor	fine to coarse	N/O	corals	bivalves, gastropods	Gastrochaenolites Entobia Trypanites	Patch reefs
Skeletal Grainstone	H, MOA, MOC, MON, TS, CYC, U, CNP, GC, PWA,PWD, SD, SDC	skeletal grainstone	moderate	fine to coarse	moderate burrowing	none	corals, bivalves	Polykladichnus Skolithos	Inter-reef
Coral B	GTP, LSP, SPB, RWP, CPA, HMB, TC, SBJ, IP, ML, PP, TJU, SB, SH, EOT, TOT, CDS, PL, ER, AS, MS, AB, AC, DP, WB, TF, BT	coral boundstone	poor	fine to coarse	N/O	corals	gastropods, red algae	N/O	Reef tract
Well sorted Skeletal Grainstone	SBB, SBD, ACB, ACF, ABB, ABC, TFB, MS	skeletal grainstone	well	fine to medium	N/O	none	corals	N/O	Reef channel
Moderately Burrowed Grainstone	SC, L, M, N, PBQ, BQ	ooid grainstone	well	fine to medium	laminated moderate burrowing	none	none	Ophiomorpha Polykladichnus Skolithos Conichnus	Subtidal
Highly Burrowed Grainstone	SC, LSC, BQ, PBA, PBQ	ooid grainstone	well	fine to medium	high burrowing	none	none	Ophiomorpha Polykladichnus Skolithos Planolites	Subtidal
Unidirectional Cross-bedded Grainstone	SC	ooid grainstone	well	fine to medium	unidirectional high-angle cross-bedding low burrowing	none	none	Polykladichnus Skolithos Conichnus Bergaueria Psilonichnus	Subtidal
Multidirectional Cross-bedded Grainstone	SC, LSC, PBQ, PBA, PMP, SB, SBA, SBF, ACA, ACH, WRS, BQ	ooid grainstone	well	fine to medium	multidirectional high-angle cross-bedding moderate burrowing	none	none	Ophiomorpha Skolithos	Upper shoreface
Lithoclast Rudstone	SC	lithoclast rudstone	moderate	fine to medium	high burrowing	none	none	Ophiomorpha Polykladichnus Conichnus	High energy subtidal
Bioclast Floatstone	SC	bioclast floatstone	moderate	fine to medium	high-angle cross-bedding moderate burrowing	none	corals, bivalves	Ophiomorpha Polykladichnus Skolithos	High energy subtidal
Laminated Grainstone	LSC, PBQ, PBA, BQ, SBA	ooid grainstone	well	fine to medium	laminated to low-angle cross-bedding	none	none	none	Foreshore-backshore

Table 2. Summary of lithology, fossils, and trace fossils of the facies in the Ironshore Formation on Grand Cayman. N/O = not observed due to poor exposure. * Trace fossils in Coral A Facies from Jones and Pemberton (1988a, 1988b); all other trace fossils from Pemberton and Jones (1988) and Jones and Pemberton (1989).

This mollusc assemblage, however, is also indicative of a lagoonal environment. Corals are slightly more abundant in this facies than in Bivalve Facies A (Hunter and Jones, 1988).

The dominant allochems in the matrix between the bivalves are micritized skeletal grains and Halimeda fragments, with lesser amounts of foraminifera, red algae, mollusc, and coral fragments (Fig. 4C).

Coral Facies A

This facies, dominated by a diverse assemblage of corals (Hunter and Jones, 1988), occurs in patches up to 300 m in diameter on the western part of Grand Cayman. This facies, which also contains a diverse assemblage of molluscs, occurs at Barker's (MOS), Morgan's Harbour (MH), localities B, C, D, E, F, G, I, J, and K near Salt Creek (Fig. 3), the Cayman Yacht Club (CYA, CYB, CYC), the Pump Station (PSI) along West Bay Road, localities A, VV, and YY near the cinemas, Walker's Road (WKR), Paul Bodden Quarry (PBA, PBQ), and Selkirk Drive (SDA, SDB - Fig. 1B). These patches of coral, considered to be patch reefs, were briefly mentioned by Brunt et al. (1973) and described by Woodroffe et al. (1980).

Coral Facies A is a coral floatstone with a grainstone matrix (Table 2). The abundant, diverse coral fauna of the patch reefs is

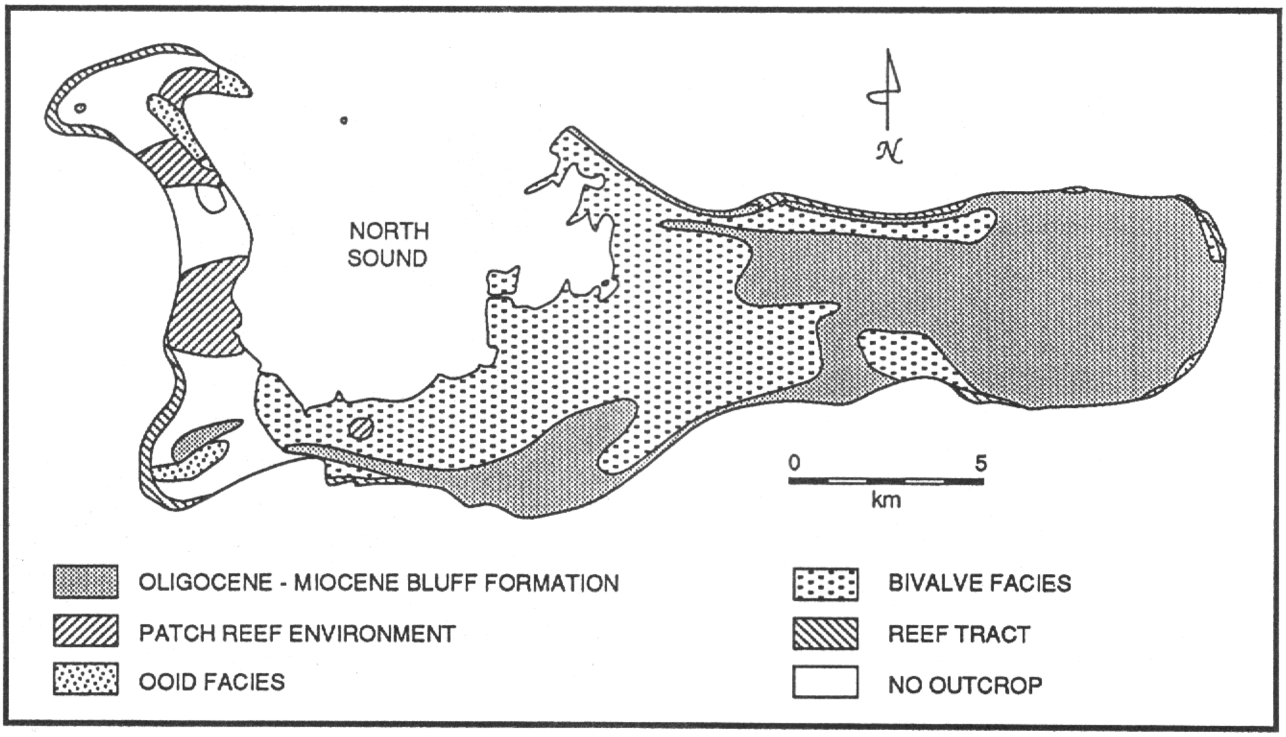

Figure 2. Facies map of the Ironshore Formation.

dominated by Montastrea, Diploria, Porites, Siderastrea, and Agaricia (Fig. 5 - Hunter and Jones, 1988). The patch reefs vary from 2-3 m in diameter at Walker's Road (WKR) and Paul Bodden Quarry (PBA, PBQ) to over 300 m in diameter near Salt Creek (Fig. 3). The amount of coral varies from 20-30% in the reefs at localities MOS, VV, and YY to 50-60% in the reef at localities C and D. Coral diversity in the patch reefs varies from nearly mono-specific (e.g. Walker's Road - WKR, Paul Bodden Quarry - PBQ, or locality I), to high diversity (e.g. 21 species at Cayman Yacht Club - CYC). Many of the larger patch reefs have a distinct zonation, being dominated by massive and hemispherical corals (Montastrea, Diploria, and Siderastrea) in the center of the reefs and branching corals (Porites) and cementing bivalves (Chama and Pseudochama) on the outer parts of the reef. All the corals found in the patch reefs are capable of significant sediment rejection (Hubbard and Pocock, 1972; Hunter and Jones, 1988).

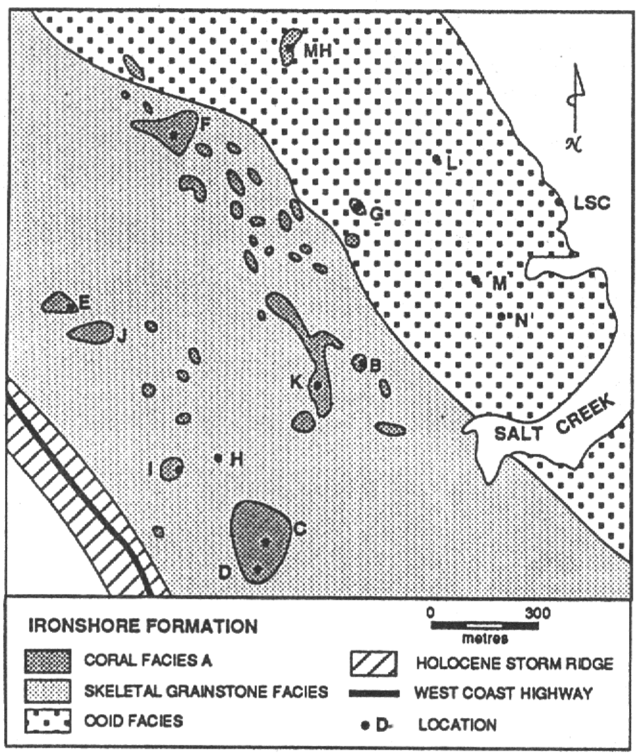

Figure 3. Paleogeographic map of a portion of the western peninsula of Grand Cayman (modified after Woodroffe et al., 1980).

Coral Facies A contains a diverse assemblage of molluscs (Woodroffe et al., 1980; Cerridwen, 1989), with 148 species of molluscs recorded by Cerridwen (1989). The mollusc fauna of the patch reefs is dominated by forms which cemented themselves to hard substrates (e.g. Chama spp. and Pseudochama radians) or lived in crevices between the corals (e.g. Arca spp. and Barbatia spp. - Cerridwen, 1989). Many reef localities include molluscs which are found in the associated sediments just off the patch reef, including Americardia guppyi, Chione spp., Codakia spp., Ervilia concentrica, Crassinella martinicensis, Linga pensylvanica, Pitar fulminatus, and Cerithium spp.

The skeletal sand between the corals is usually poorly sorted (Fig. 4D), but locally well sorted. The dominant allochems are micritized skeletal grains. The remainder of the allochems are Halimeda, mollusc, red algae, and coral fragments along with lesser amounts of echinoid fragments, worm tube fragments, and foraminifera. Comparison of well preserved fecal pellets (Fig. 6A), with modern thalassinid anomuran crustacean fecal pellets (Moore, 1932, 1939; Shinn, 1968), suggests that they are crustacean pellets. These pellets indicate the importance of burrowing crustaceans around the patch reefs.

Many large hemispherical corals, such as Montastrea annularis, M. cavernosa, Diploria strigosa, D. labyrinthiformis, and

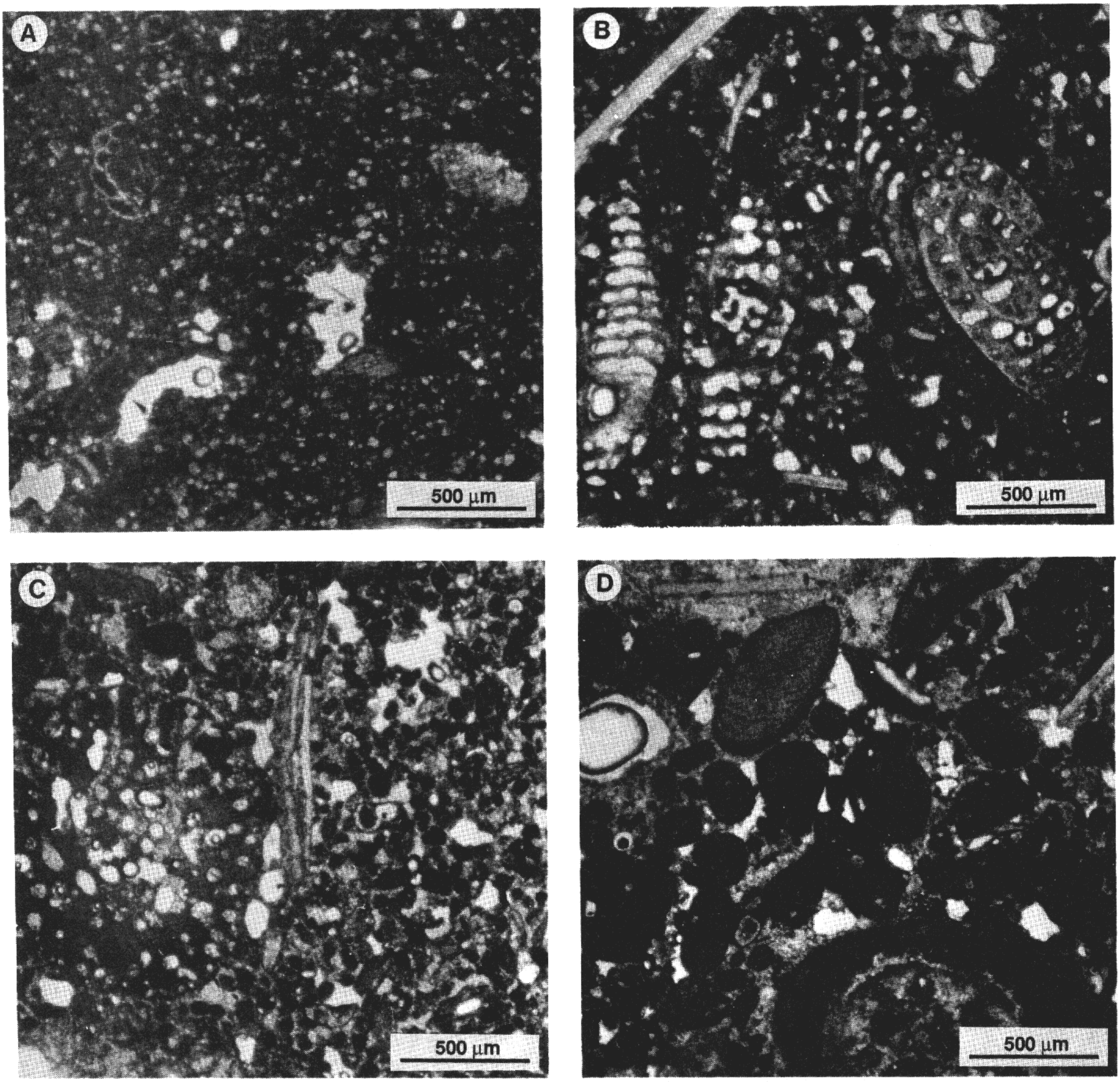

Figure 4. A) Skeletal wackestone in Bivalve Facies A. Sample CI 2236, locality TSE. B) Abundant Peneroplid foraminifera in Bivalve Facies A. Sample CI 2208, locality TSE. C) Skeletal packstone in Bivalve Facies B. Sample CI 2198, locality OGA. D) Poorly sorted skeletal grainstone in Coral Facies A. Sample CI 1976, locality B.

Siderastrea siderea, were extensively bored by Lithophaga (Jones and Pemberton, 1988a, 1988b), sponges, and worms. The Lithophaga (1) bored into dead colonies, because the borings are found around the entire colonies, (2) substantially weakened the coral heads thereby making them more susceptible to erosion, (3) bound the substrate by virtue of the dense calcareous linings in the borings, (4) liberated substantial amounts of calcium carbonate from the coral heads, (5) increased the rock-area available for further bioerosion by sponges, algae, and fungi, and (6) by virtue of the empty borings provided protected sites for sediment accumulation (Jones and Pemberton, 1988a, 1988b).

Skeletal Grainstone Facies

Between the patch reefs on the west side of Grand Cayman, is the Skeletal Grainstone Facies (Table 2). This facies is present at Barker's (MOA, MON, MOC) near the patch reef at MOS, The Shores (TS), locality H near the patch reefs at B, C, D, E, F, G, I, J, and K near Salt Creek (Fig. 3), Canal Point (CNP), Golf Course (GC), locality U near the patch reefs at A, VV, and YY near the cinemas, localities PWA and PWD near the Public Works Department, and Selkirk Drive (SD, SDC, SDD) near the patch reefs (SDA, SDB - Fig. 1B).

FACIES	CORAL A					CORAL B						
LOCATION	SB	SH	DP	TF	BT	C,D	F	MH	B	K	SD	I
Stephanocoenia michelini					R							
Acropora palmata	S	A	A	S								
Acropora cervicornis	S	A	A	C	C							
Pocillopora sp.	C		R									
Agaricia agaricites		S	S	S	S	C	S	R		S	S	R
Agaricia fragilis				R		S	R					R
Leptoseris cucullata											R	
Siderastrea siderea		S	C		S	C	C	C		S	C	
Siderastrea radians				S							S	
Porites astreoides		S	S	S	S	S	S	C	S	S	S	
Porites porites	A	C	C	A	C	A	C	S	C	A	S	A
Favia fragum	S	S	S	S	S	S	S	S	S		S	
Diploria clivosa	C		C				S	S				
Diploria strigosa	C	C	C	C	C	C	C	A	C	C		
Diploria labyrinthiformis	S	S	S	C	S	S	C	C	C	S		
Manicina areolata	S	S	R	R	S	S	S	R	S	S	S	S
Colpophyllia natans	S	S	S		S	S	C					
Montastrea annularis	A	A	A	A	A	A	C	A	A	A	A	C
Montastrea cavernosa	S	C	C	S	C		R	C				
Oculina diffusa	R										R	
Meandrina meandrites			R	R	R							
Dichocoenia stokesi			R	R	R						R	
Dendrogyra cylindrus	C	C	R		S							
Mussa angulosa					R							
Scolymia cubensis						R	R				R	
Isophyllastrea rigida	R	R	R	R				R				
Isophyllia sinuosa	R		R	R	R						R	
Mycetophyllia spp.	R	S	S			C	S	R			S	
Eusmilia fastigiata				R	R	R		R		R	R	

Figure 5. Distribution of corals at selected localities as Coral Facies A and B on the western part of Grand Cayman. A = abundant; C = common; S = Scarce; R = Rare. (Modified after Hunter and Jones, 1988).

The Skeletal Grainstone Facies contains a diverse assemblage of molluscs (Woodroffe et al., 1980; Cerridwen, 1989), with 118 species of molluscs recorded by Cerridwen (1989). These molluscs are usually articulated and well preserved, although some of the thin shelled molluscs have been broken (Cerridwen, 1989). This mollusc assemblage is dominated by Chione spp., Codakia spp., Crassinella martinicensis, Linga pensylvanica, and Cerithium spp. Locally, these limestones are highly bioturbated, with Skolithos and Polykladichnus being abundant.

The limestone between the patch reefs is usually a grainstone, but is locally a packstone. The allochems, dominated by micritized skeletal grains, are usually poorly to very poorly sorted, but in some areas are moderately to moderately well sorted. Other allochems include mollusc, coral, red algae, and Halimeda fragments, and rare foraminifera, echinoid and worm tube fragments, and pellets. Less Halimeda fragments are present in this facies than in Bivalve Facies A or B. In some areas (e.g. Canal Point, CNP) ooids with thin oolitic coatings are present. In fact, there is probably a transition between the Skeletal Grainstone Facies and the Highly Burrowed Grainstone Facies. The sediment surrounding the reefs at Selkirk Drive (SD, SDC, SDD) is finer, consisting of sediment very fine to medium grained in size.

Corals are rare in this facies. The corals were deposited as rubble from the patch reefs or isolated growth on the sea floor.

Coral Facies B

This facies, which contains a diverse coral fauna (Fig. 5; Hunter and Jones, 1988), occurs in a linear outcrop belt along the west, northwest, and southwest coasts of Grand Cayman. This facies is present at West Bay (ABA, ABB, ABC, ABD, ACA, ACB, ACC, ACD, ACE, ACF, ACG, ACI), Dolphin Point (DP, DPQ, DPA, DPB, DPC, DPD, DPE, DPF), West Bay (WBA, WBB), Turtle Farm (TF, TFN, TFA, TFB), Birch Tree Hill (BTH, BTA, BTB, BTC, BTD, BTE, BTF), Georgetown (BK, MS, AS), Eden Rock (ERN, ERS), Cayman Diving School (CDS), Parrot's Landing (PL), Sunset House (SH, SHA, SHB), Esso Oil Tanks (EOT), Texaco Oil Tanks (TOT), Smith's Barcadere (SB, SBA, SBB, SBC, SBD, SBE, SBF, SBG), Prospect Point (PP, TJU), Spotts Bay Jetty (SBJ, SBK), Frank Sound (ML), Cottage Point (CPA), Half Moon Bay (HMA, HMB), Ironshore Point (IP), Tortuga Club (TC), Rodger's Wreck Point (RWP), Spotter Bay (SPB), Little Spot Point (LSP), and Grape Tree Point (GTP) (Fig. 1B). This linear outcrop of corals is considered to be a reef tract. Channels which are filled with the Well Sorted Skeletal Grainstone Facies transect the reef tract.

Facies of the reef crest have been eroded through much of the reef tract. The preserved portion of the reef tract is probably back-reef in origin, because of substantial erosion of the Ironshore Formation since the Pleistocene (Hunter and Jones, 1988).

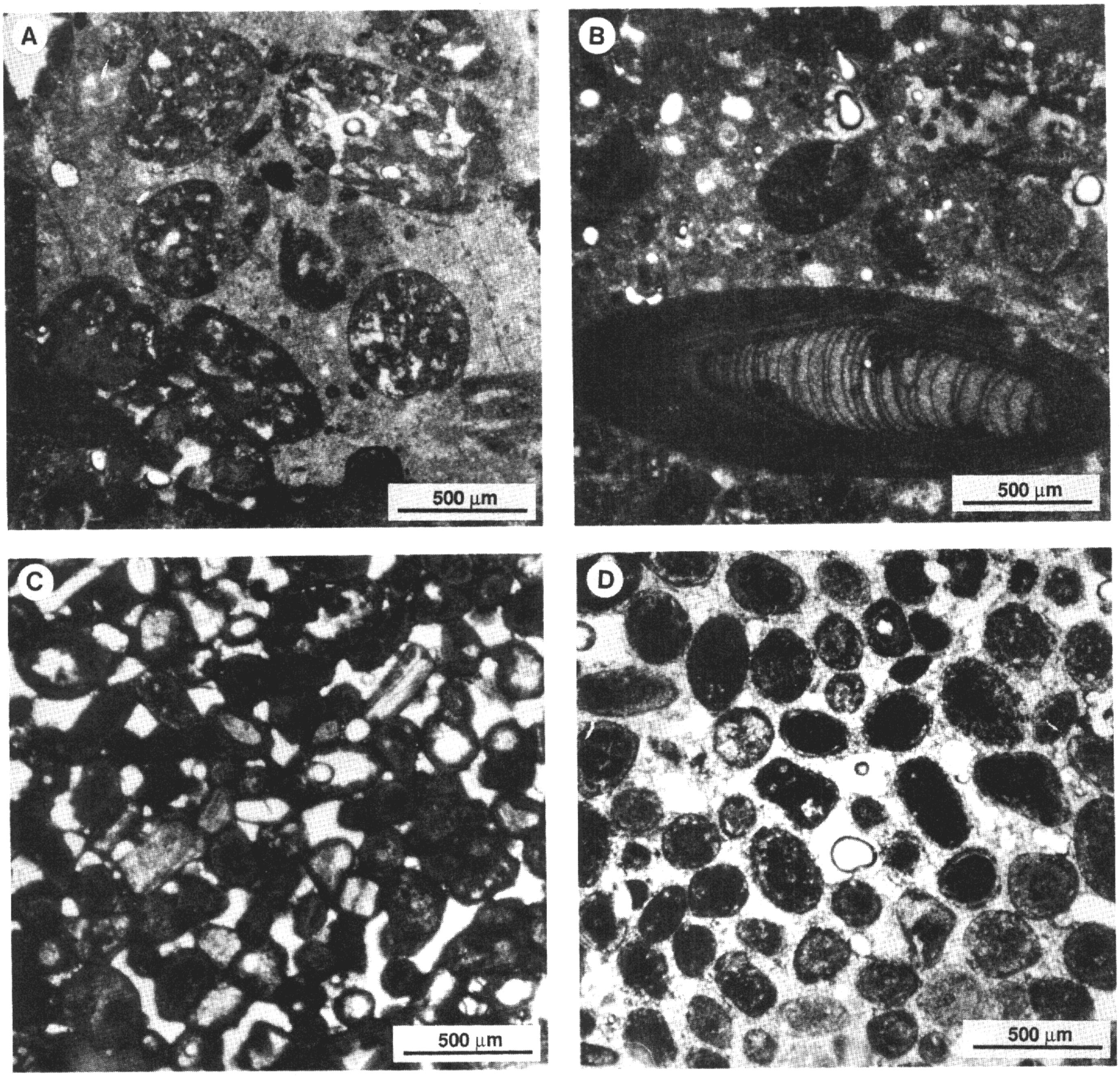

Figure 6. A) Shrimp pellets in Coral Facies A. Sample 2085, locality G. B) Poorly sorted skeletal grainstone in Coral B Facies. Sample CI 2673, locality WBB. C) Well sorted ooid and skeletal grainstone in Well Sorted Skeletal Sand Facies. Sample CI 1753, locality ABB. D) Ooids with a thin oolitic coating in the Moderately Burrowed Grainstone Facies. Sample CI 1324, locality SC.

This facies is a coral framestone to rudstone with a grainstone matrix (Table 2). The sediment surrounding the corals is usually a poorly sorted carbonate sand (Fig. 6B), but is locally well sorted. The dominant allochems are micritized skeletal grains, coral and red algae fragments, with lesser numbers of foraminifera, Halimeda, and mollusc fragments. Between the abundant coral skeletons is a diverse mollusc fauna, dominated by gastropods and lesser numbers of bivalves (77 species - Cerridwen, 1989).

Coral diversity in the reef tract varies from nearly monospecific patches of Porites porites, Pocillopora sp., or Dendrogyra cylindrus (e.g. Smith's Barcadere SBB, SBD, SBE, SBF) to areas of high diversity (e.g. 21 species at Dolphin Point DP - Fig. 5). The corals, which occur in the reef tract but not in the patch reefs, are Meandrina meandrites, Dendrogyra cylindrus, Pocillopora sp., Acropora cervicornis, and A. palmata. The Acropora spp. and M. meandrites are incapable of sediment rejection (Hubbard and Pocock, 1972).

Different coral communities (Fig. 5), occur in different areas of Coral Facies B. These communities are:

(1) Acropora community, dominated by A. cervicornis and A. palmata;
(2) Porites community, dominated by P. porites;

(3) Dendrogyra community, dominated by D. cylindrus and Pocillopora sp.;
(4) Montastrea community, dominated by hemispherical corals of M. annularis, M. cavernosa, Diploria spp., and Siderastrea siderea; and
(5) Diploria community, dominated by D. clivosa and D. strigosa.

Stromatolites formed around many coral fragments (Pocillopora sp. and Acropora cervicornis) in this facies. These stromatolites, up to 3 cm thick and 10 cm long, are composed of alternating layers of carbonate silt and micrite, and darker algal-rich layers. Some layers within the stromatolites are encrusted by foraminifera (Homotrema and Carpentaria) or red algae. The structure of these stromatolites suggest that they were formed in a low energy environment.

Well Sorted Skeletal Grainstone Facies

This facies, located along the reef tract, consists of well sorted ooid and skeletal grainstones, with few corals. This facies is present at Smith's Barcadere (SBB, SBD), West Bay (ABB, ABC, ACB, ACF), and the Turtle Farm (TFB - Fig. 1B). This facies, restricted to areas 10-25 m wide, is interpreted to have been deposited in reef channels. Corals are rare, being mostly debris from the nearby reef.

This facies consists of well sorted ooid or skeletal grainstones (Table 2). The ooids have thick cortical layers making up approximately 50% of the ooid (Fig. 6C). The nuclei of the ooids are coral and mollusc fragments and micritized skeletal grains. Other allochems include coral, red algae, and mollusc fragments.

Moderately Burrowed Grainstone Facies

This facies, which consists of moderately burrowed ooid grainstones (Table 2), is present at Salt Creek (SC). Jones and Pemberton (1989 - Table 1) divided this facies based on the thickness of the laminations.

The dominant allochems in this facies are ooids. They average 125-250 µm in diameter (Fig. 6D), although they are up to 550 µm in diameter (Jones and Goodbody, 1984). The ooids typically have a (1) slightly irregular ovoid outline, (2) matt surface, (3) large nucleus, and (4) thin cortex of only a few cortical layers (Jones and Goodbody, 1984; Jones and Pemberton, 1989). Small skeletal fragments of mollusc shells, corals, and Halimeda form less than 5% of this facies. Jones and Goodbody (1984) suggested that the thin oolitic coatings on the ooids may have been developed because of bacterially induced calcite precipitation intimately associated with pellets produced by Callianassa.

The nuclei of the ooids are masses of dense, dark-coloured cryptocrystalline calcite or aragonite. These were considered to be fecal pellets (Jones and Goodbody, 1984), because the nuclei of the ooids (1) have an ovoid shape comparable to that associated with pellets, (2) have a high organic content, (3) are well sorted, (4) contain detrital fragments of skeletal material that are randomly scattered throughout the nuclei, and (5) many contain small (30-50 µm) circular to ovate openings that are comparable to canal systems found in pellets produced by Callianassa (Shinn, 1968).

These ooids are different from the ooids in the Well Sorted Skeletal Grainstone Facies. The ooids from the Moderately Burrowed Grainstone Facies have thin cortical layers (as opposed to thick cortical layers) and have pellets as nuclei (as opposed to skeletal fragments as nuclei).

This facies, which is moderately burrowed (5 on the scale of Frey and Pemberton, 1985 - Table 2), has low angle to parallel laminations (Jones and Pemberton, 1989). The Ophiomorpha are dominantly vertical in the upper part of this facies and usually extend down to the lower section of the outcrop where they become horizontal. This facies probably originated in a quiet-water lagoon (Jones and Goodbody, 1984; Jones and Pemberton, 1989).

Highly Burrowed Grainstone Facies

This facies, characterized by a sequence of highly burrowed ooid grainstones, is present at Botabano Quarry (BQ), Paul Bodden Quarry (PBQ, PBA), Salt Creek (SC), and Little Salt Creek (LSC).

The dominant allochems are ooids (Table 2), similar to those in the Moderately Burrowed Grainstone Facies. These oolitic limestones have been moderately to highly burrowed (7-9 on the scale of Frey and Pemberton, 1985), with vague laminations remaining. This facies is interpreted to be deposited in a quiet-water lagoon (Jones and Pemberton, 1989).

Unidirectional Cross-bedded Grainstone Facies

This facies, characterized by a sequence of unidirectional cross-bedded ooid grainstones, is restricted to Salt Creek (SC). Woodroffe (1988) attributed a subaerial origin to this facies by incorrectly citing and interpreting information from Jones and Goodbody (1984).

The ooids (Table 2) in this facies are similar to those in the Moderately Burrowed Grainstone Facies. At the base of this facies, there are scattered tabular lithoclasts, up to 30 cm x 30 cm x 10 cm. They are composed of well sorted cemented ooids similar to those in the matrix. Although their appearance suggests derivation from beachrock, they contain no features that would support this suggestion (Jones and Pemberton, 1989).

The ooid grainstones are characterized by high-angle cross-bedding, locally with back-flow ripples (Jones and Pemberton, 1989). This facies has low burrowing (1-2 on the scale of Frey and Pemberton, 1985), but the trace fossil assemblage is unequivocally marine in origin (Pemberton and Jones, 1988; Jones and Pemberton, 1989). This facies is interpreted to be deposited in a (tidal?) channel (Jones and Pemberton, 1989).

Multidirectional Cross-bedded Grainstone Facies

The Multidirectional Cross-bedded Grainstone Facies, occurs at Salt Creek (SC), Little Salt Creek (LSC), Botabano Quarry (BQ), West Bay (ACA, ACH), Palmetto Point (PMP), Smith's Barcadere (SBA, SB, SBF), Paul Bodden Quarry (PBQ, PBA), and Walker's Road School (WRS - Fig. 1B). It overlies the lagoonal deposits of the Skeletal Grainstone, Moderately Burrowed Grainstone, and Highly Burrowed Grainstone facies and the reefal deposits of the Coral A and B facies.

This facies, containing well sorted ooids, similar to those in the Moderately Burrowed Grainstone Facies, is characterized by trough cross-bedding, planar cross-bedding, and parallel laminations (Jones and Pemberton, 1989). These oolitic limestones, with low burrowing (3 on the scale of Frey and Pemberton, 1985 - Table 2), are interpreted to be upper shoreface (Jones and Hunter, in press).

Lithoclast Rudstone Facies

This facies, characterized by irregular-shaped lithoclasts with a well sorted ooid grainstone matrix, is only present at Salt Creek (SC). These lithoclasts, up to 10 cm x 10 cm x 10 cm, consist of well sorted cemented ooids similar to those in the matrix. These lithoclasts extend though the entire thickness of the facies. There are no sedimentary structures (Jones and Pemberton, 1989), because it is highly burrowed (8 on the scale of Frey and Pemberton, 1985). These rudstones were deposited at the base of a high-energy channel (Jones and Pemberton, 1989).

Bioclast Floatstone Facies

These bioclast floatstones occur only at Salt Creek (SC) as a channel fill. The bioclasts of molluscs and corals are in a matrix of well sorted ooids, similar to those in the Moderately Burrowed Grainstone Facies. At the base of this facies there are scattered tabular lithoclasts, similar to those in the Unidirectional Cross-

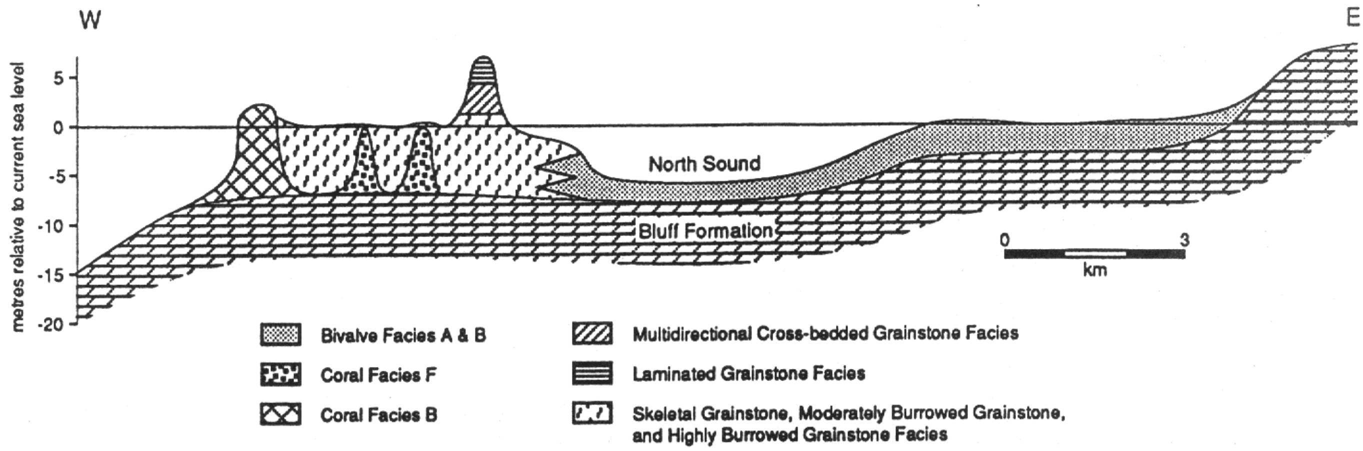

Figure 7. Schematic east-west cross-section across the western half of Grand Cayman showing the lateral and vertical relationships of the main facies in the Ironshore Formation (modified after Jones and Hunter, in press).

bedded Grainstone Facies. These limestones contain large scale cross-bedding, locally with planar laminations (Jones and Pemberton, 1989), and are interpreted to have been deposited in a channel (Jones and Pemberton, 1989).

Laminated Grainstone Facies

These laminated ooid grainstones are present at Little Salt Creek (LSC), Paul Bodden Quarry (PBA, PBQ), Botabano Quarry (BQ), and Smith's Barcadere (SBA - Fig. 1B) overlying the Multidirectional Cross-bedded Grainstone Facies. At Paul Bodden Quarry (PBA) they attain a maximum elevation of 6.5 m above present-day sea level.

These grainstones, dominated by well sorted ooids similar to those in the Moderately Burrowed Grainstone Facies, are characterized by horizontal to low-angle laminations. No burrows have been observed, even though all outcrops were examined in great detail. This facies of subparallel to low-angle cross-bedded laminated grainstones is interpreted to be a foreshore (beach) deposit and indicative of sea level (Jones and Hunter, in press).

DISCUSSION

Erosion of the Bluff Formation between middle Miocene and late Pleistocene times produced a highly irregular topography, upon which the limestones of the Ironshore Formation were deposited (Jones and Smith, 1988). Although the Ironshore Formation occurs in small embayments on the east, south, and north coasts of Grand Cayman, the main area of deposition was in a large lagoon that covered the western half of Grand Cayman. This lagoon was named the Ironshore Lagoon (Fig. 1C, 7 - Hunter and Jones, 1988).

In the interior of the lagoon, Bivalve Facies A and B were deposited in quiet shallow water conditions. These sediments were deposited in either grass meadows or sediment banks, similar to those in North Sound. The western portion of the Ironshore Lagoon was characterized by patch reefs (Coral Facies A) and inter-reef sediments (Skeletal Grainstone, Moderately Burrowed Grainstone, and Highly Burrowed Grainstone). These patch reefs are similar to patch reefs found in many lagoons around Grand Cayman today. At the margin of the Ironshore Lagoon was an extensive barrier reef with a series of tidal channels (Well Sorted Skeletal Grainstone) through the reef. Little of the reef crest and shallow fore-reef sediments are now preserved, but an extensive reef tract (dominantly shallow back-reef) with a diverse assemblage of corals (Coral Facies B) is still preserved.

Subsequent to the deposition of the temporal equivalent facies described above, the lagoon was filled by ooid grainstones to a maximum elevation of 6.5 m above present day sea level. This shallowing upward sequence comprises (1) lagoonal deposits described above, (2) an upper shoreface facies (Multidirectional Cross-bedded Grainstone Facies), and (3) a foreshore-backshore deposit (Laminated Grainstone Facies). The Laminated Grainstone Facies occurs 4-6.5 m above sea level and puts constraints on the height of sea level during the Sangamon.

The outcrop of the Ironshore Formation at Salt Creek contains a good exposure of a series of channels, probably formed by storm activity (Jones and Pemberton, 1989). In these channels the Unidirectional Cross-bedded Grainstone Facies, Lithoclast Rudstone, and Bioclast Floatstone were deposited.

CONCLUSIONS

Detailed study of the Ironshore Formation on Grand Cayman has shown that:

(1) it can be divided into thirteen distinct facies, representing environments from a lagoon to a reef tract,
(2) the coral communities in the patch reefs and the reef tract can be differentiated by the presence or absence of corals incapable of sediment rejection, and
(3) sea level, 125,000 years ago, can be estimated at about 6 m above present day sea level.

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